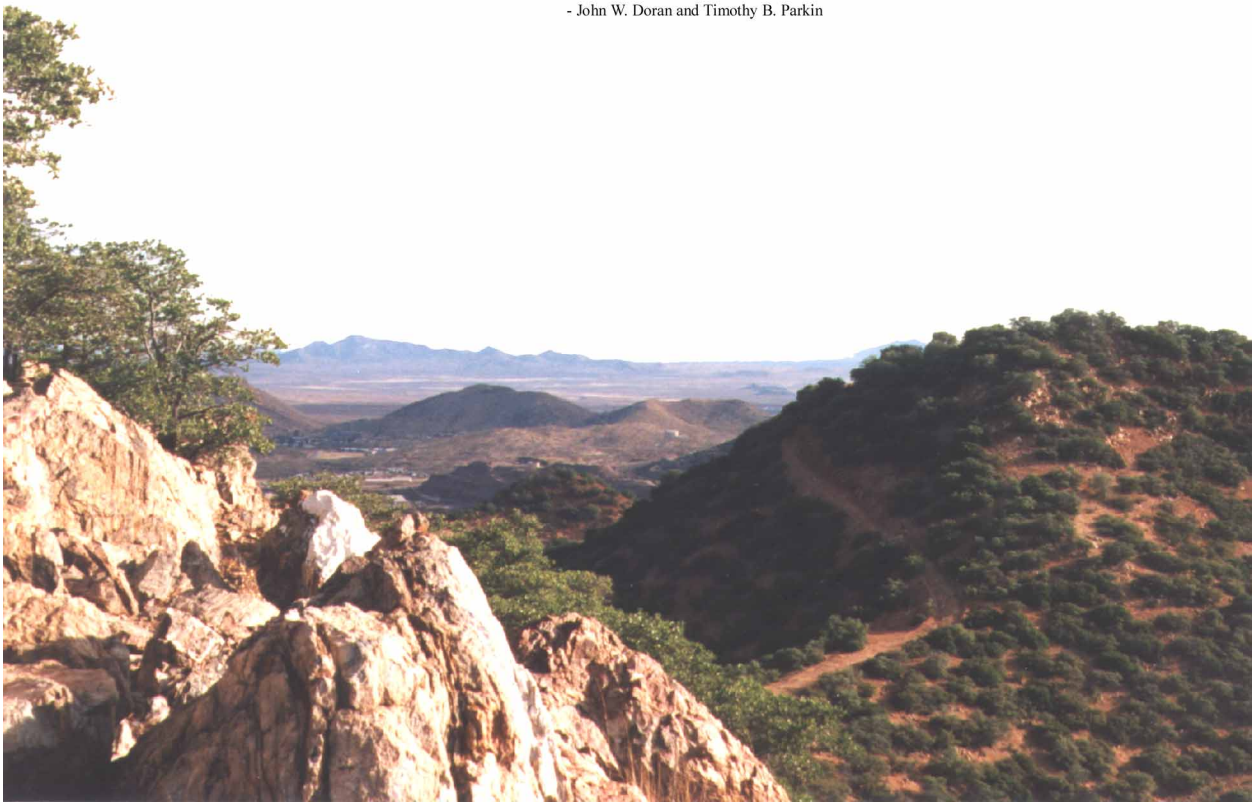
SECTION 1

WHAT IS SOIL

The thin layer of soil covering the earth's surface represents the difference between survival extinction for most terrestrial life

- John W. Doran and Timothy B. Parkin



1.1 Introduction

Soil is the biologically active, structured porous medium that has developed below the continental land surface on our planet. Many scientists have described soil as the skin of the Earth and have studied it in great detail because its properties are different from the properties of each of its components. The science of pedology emphasizes the study of soil as a natural phenomenon on the surface of the Earth. Therefore, the pedologist is interested in the appearance of the soil, its mode of formation, its physical, chemical and biological composition, and its classification and distribution (Bridges, 1997). The pedosphere is the envelope of the Earth where soils occur and soil forming factors are active (Ugolini and Spaltenstein, 1992).

The pedosphere only develops when there is a dynamic interaction between the atmosphere, biosphere, lithosphere and the hydrosphere (Fig. 1.1). The pore space in soil is either filled with air or water, while the solid phase consists of the mineral (lithosphere) and organic living (biosphere) and nonliving components. Soil is the foundation for life in terrestrial ecosystems and affects the energy budget, water exchange, nutrient cycling and ecosystem productivity.

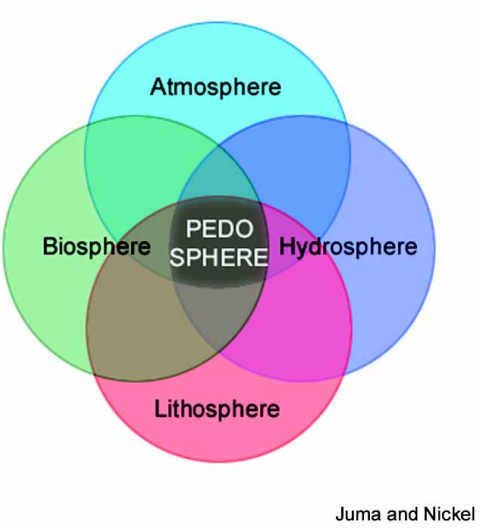


Fig. 1.1. Relationships between the pedosphere, atmosphere, hydrosphere, lithosphere and biosphere.

Over the past 50 years, there has been tremendous development in different disciplines of Earth Sciences. Advances in space exploration, a holistic view of the Earth, instrumentation and information technology have pushed the scientific research and teaching agendas from the discovery of fundamental concepts in individual disciplines to the integration of data and the formulation of hypotheses for larger, complex systems. The study of the connections and the interactions between the atmosphere, hydrosphere, biosphere, cryosphere, pedosphere, solid earth, and near space is emerging as the foundation for Earth System Science. The Earth System Science approach is now being used to assess the impact of human activities on global environmental change.

In 1996, the Earth System Science Education group in the United States initiated a formal collaborative effort to create Earth System Science educational modules for the following topics (Johnson et al., 1997):

1. **Earth Energy Budget:** This module focuses on the analysis of environmental/earth systems phenomena partially as a problem of the transformation and flow of energy within organized systems. Potential areas of application include: global climate change; ecosystem energetics; energy flow and material cycles of carbon, hydrogen, nitrogen and phosphorus; human energy infrastructure; ocean dynamics; and planetary formation and evolution. Soils strongly impact global environmental change, ecosystem energetics, energy flow and material cycles.

2. **Atmospheric Ozone:** The atmosphere is the air surrounding the Earth. It extends up to 200 km into the atmosphere and its composition changes over time. The atmosphere layer at 15-30 km altitude has an ozone concentration of 1-10 parts per million. The ozone layer limits the amount of ultraviolet radiation reaching the ground surface. Ultraviolet radiation can cause damage to certain plant cells and affect the biotic activity in the pedosphere.

3. **Hydrological Cycle:** This module focuses on the global hydrological cycle, local hydrological cycle, and human consumption of water. Key systems concepts include equilibrium, feedback, closed versus open systems, residence times and the nature of transient responses to perturbations. The local hydrological cycle is strongly controlled by soil and landscape properties.

4. **The Biosphere:** The biosphere is the whole region of the Earth's surface, the ocean and the air that is inhabited by living organisms. The key emphases for this module are: putting the biosphere into a time perspective - considering how organisms and the earth evolved together through interchanges of energy and pressure; and putting the biosphere into a spatial perspective by examining the effect of the atmosphere, hydrosphere, lithosphere and pedosphere on the distribution of biomes and ecosystems within the earth.

5. **Biogeochemical Cycles:** The global carbon cycle is a key element of the Earth System and plays an important role in determining Earth's climate. It is interconnected with the global hydrologic cycle and the planetary energy cycle to determine climate. It is also interconnected with the global cycles for elements such as nitrogen, phosphorus, sulfur, and heavy metals. The pedosphere supports life in terrestrial ecosystems and impacts the cycling of elements and energy flow of the Earth System.

6. **Soil Processes, Land Use, Land Cover Change:** This module focuses on: soils and their function in terrestrial ecosystems; the linkage between soils and the biosphere; the different time scales in which soils regenerate and humans degrade soils; the impact of land use practices; and the long-term economic, ecological, and human consequences of good and poor soil management.

7. **Economics, Sustainability and Natural Resources:** This module focuses on analyses of linkages between economics and environmental change on local, regional and global scales and addresses the role of economic analysis in the design and implementation of environmental policy. The sustainable use of renewable natural resources (soil, air, water, microbes, plants and animals) in the context of non-renewable resources (oil, natural gas, natural forests) is a major environmental issue facing human society at local, regional and global levels.

8. **The Antarctic:** This module focuses on Antarctica, illustrating the interdisciplinary processes of glaciology, geology, biology, and chemistry, which influence Earth phenomena and human activities in an international context.

9. **El Niño - Southern Oscillation:** El Niño is a disruption of the ocean-atmosphere system in the tropical Pacific having important consequences for weather around the globe. Among these consequences are increased rainfall across the southern tier of the US and in Peru, which has caused destructive flooding, and drought in the West Pacific, sometimes associated with devastating brush fires in Australia. The change in weather patterns impacts water storage and plant growth in terrestrial ecosystems.

10. **Observing Systems and Remote Sensing:** The use of radars, sonars, spectroscopy, airborne and satellite photography allows for the gathering of information without actual physical contact with what is being observed. Passive satellite remote sensing involves the measurement of electromagnetic radiation (i.e. light, heat) upwelling to a satellite instrument. By examining the electromagnetic spectrum of radiation emitted from the sun, or emitted from the Earth system, as it interacts with the Earth system, one may discover signal information for different processes or changes in the atmosphere, oceans, or on Earth's surface. Some applications connected to soil and landscape processes include land use, land cover change, water pollution and flooding.

11. **Human Population - Environment Interactions:** This module focuses on issues of human population and environmental interaction and addresses issues such as the dynamics of human population, the consumption of natural resources, social dimensions, and industrial ecology. Integration of these issues could lead to assessment of the human impact on the environment.

12. **Health and Climate Change:** This module focuses on the impact of climate change on human health. Climate change affects the moisture and temperature regimes, the intensity of ultraviolet radiation on the Earth's surface and other processes which may affect ecosystem health. These in turn could impact human health.

13. **Earth System History:** This modules provides an overview of the scales and development of solid earth, oceans, atmosphere and life with focus on events or trends that are particularly important to present-day earth system components and processes. It emphasizes the inter-relatedness of life and earth processes. Human-induced climate changes will be superimposed on the background of natural variability and variations of temporal, spatial, and

energy scales of processes in all aspects of the Earth systems.

14. **System Concepts and the Earth System:** This module focuses on the applicability of systems theory to the real world, systems concepts and terminology, and an introduction to integrative systems modeling. Systems theory focuses on the arrangement of and relations between the parts which connect them to the whole. Mathematical systems theory is applied to problems in such diverse fields as engineering, computing, ecology, and management.

The pedosphere is the interface between the atmosphere, lithosphere, hydrosphere and the biosphere in terrestrial ecosystems. Knowledge of the discipline of Soil Science is needed to understand ecosystem dynamics and can lead to a better understanding of the terrestrial portion of the whole Earth System.

1.2 The Pedosphere

Definitions

Atmosphere: The air surrounding the Earth. The atmosphere has no precise upper limit, but for all practical purposes, the absolute top can be regarded as being at about 200 km.

Biosphere: The part of the Earth's environment in which living organisms are found, and with which they interact to produce a steady-state system, effectively a whole planet ecosystem.

Hydrosphere: The total body of water that exists on or close to the surface of the Earth.

Lithosphere: The upper (oceanic and continental) layer of the solid Earth, comprising all crustal rocks and the brittle part of the uppermost mantle.

Pedosphere: The envelope of the Earth where soils occur and where soil-forming processes are active.

Landscape: All the natural features such as fields, hills, forests, and water that distinguish one part of the earth's surface from another part. Usually it is the portion of land or territory that the eye can see in a single view, including all its natural characteristics.

Regolith: The unconsolidated mantle of weathered rock and soil material overlying solid rock.

Soil: The naturally occurring unconsolidated material on the surface of the earth that has been influenced by parent material, climate (including the effects of moisture and temperature), macro- and micro-organisms, and relief, all acting over a period of time to produce soil that may differ from the material from which it was derived in many physical, chemical, mineralogical, biological, and morphological properties.

Soil pedon: The smallest volume of what can be called a soil. A pedon has 3 dimensions. Its lower limit is the vague and somewhat arbitrary limit between soil and "not soil". Its area ranges from 1 to 10 square meters, depending upon the variability of horizons. The shape of the pedon is roughly hexagonal.

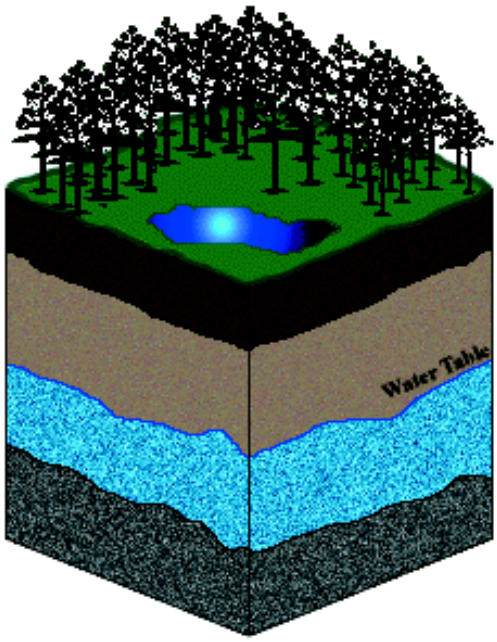
Parent material: The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of a soil has developed by pedogenic processes.

Soil solum: The upper horizons of a soil in which the parent material has been modified and in which most plant roots are contained. It usually consists of A and B horizons.

Soil horizon: A layer of soil or soil material approximately parallel to the land surface; it differs from adjacent genetically related layers in properties such as color, structure, texture, consistence, and chemical, biological, and mineralogical composition.

Concepts

The pedosphere (soil) forms when there is an interaction of the lithosphere (minerals), biosphere (life), atmosphere (air), and hydrosphere (water) (Fig. 1.2). A vertical cross-section of the ecosystem contains air, vegetation, soil and subsoil, saturated and unsaturated weathered rock (parent material from which the soil forms) and unweathered rock.



ECOSPHERE	COMPONENTS
Atmosphere	Air
Atmosphere & Biosphere	Forest Cover
Pedosphere	Soil and Subsoil Cover
Lithosphere & fresh-water Hydrosphere	Saturated & unsaturated weathered rock
Lithosphere	Unweathered rock

Juma and Nickel

Fig. 1.2. Vertical cross-section of a ecosystem showing the relationships between different landscape components.

The soil pedon is a three-dimensional body in the landscape that can be divided into four main components: air, water, mineral, and organic matter. In a practical sense, the presence of the hydrosphere, atmosphere, biosphere and lithosphere in soil is measured in terms of soil water, soil air, soil organisms, soil organic matter and mineral (inorganic) components (Fig 1.3).

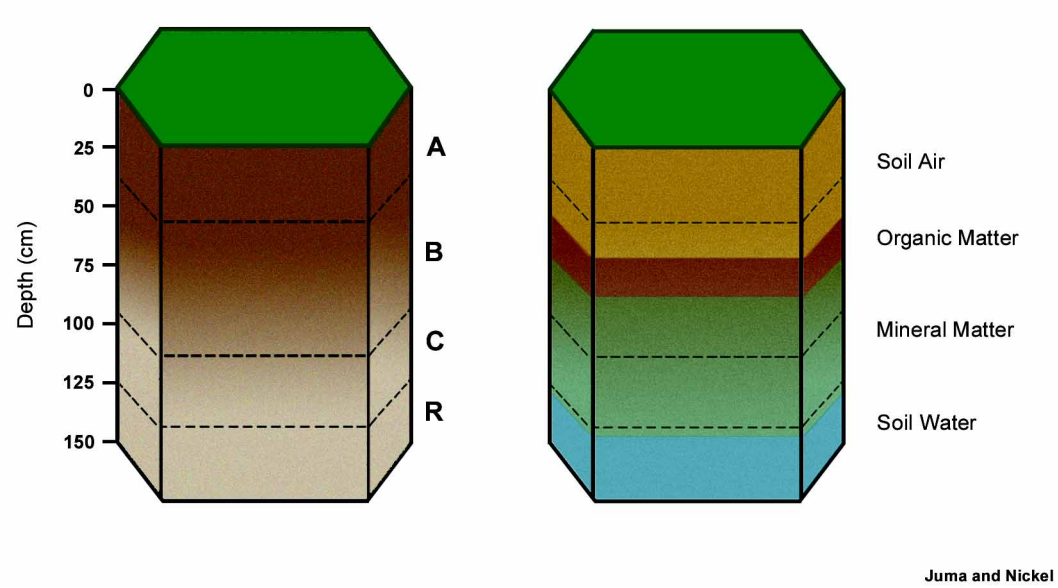


Fig. 1.3. The structure and composition of a pedon.

An image of the pedon (a three-dimensional body in a landscape) is shown in Fig 1.3a while its composition is shown in Fig 1.3b. The soil is a natural body that forms from the interaction of the atmosphere, hydrosphere, lithosphere and biosphere and has unique properties that will be discussed later. Generally, the soil air and soil water occupy about 50% of the volume of the pedon, the organic matter consisting of living organisms and their products or by-products accounts for 5% and the remainder is occupied by the mineral component. The arrangement of soil pores and soil particles, peds or aggregates into layers, called soil horizons, allows a pedologist to classify soils. The composition of soil allows soil scientists, engineers, and modelers to quantify the dynamics of gases, water and solutes occurring within the pedon. These properties will also be discussed later.

The weathering of massive rocks along planes of weakness through physical and chemical processes leads to the formation of unconsolidated residues called the regolith. The regolith occurs above the consolidated rock and is the material from which the soil forms. In places where the regolith is thin, the soil may include the entire regolith. In contrast, if the regolith is very thick, the soil occupies only its upper part. The regolith is transformed through continual physical, chemical and biological transformations into a sequence of horizontally differentiated layers called soil horizons.

The soil profile can have one to four master horizons which are named, from the surface downward, as A, B, and C horizons. The underlying consolidated rock is called R horizon. The major organic horizons are L, F, H, which are mainly forest litter in various stages of decomposition, and O, which is derived mainly from wetland vegetation. Subdivisions of horizons are labeled by adding lower-case suffixes to some of the major horizon symbols and are covered in Section 4.8.

Some pedons contain rock, R, and water, W. In some cases, a pedon may have a sequence of parent materials. In such cases, the parent materials are labeled sequentially as C, IIC, IIIC and so on. The prefix in Roman numerals specifies different kinds of parent material. Generally, the Roman numeral I is assumed for major mineral horizons in the upper part of the pedon and is not included in horizon designations.

The pedosphere proper develops at the intersection of four spheres: the lithosphere, the hydrosphere, the atmosphere and the biosphere. In nature, it is possible to encounter three-sphere and two-sphere systems in which one or two of the spheres are missing. Mattson (1938) schematically illustrated these combinations (Fig. 1.4).

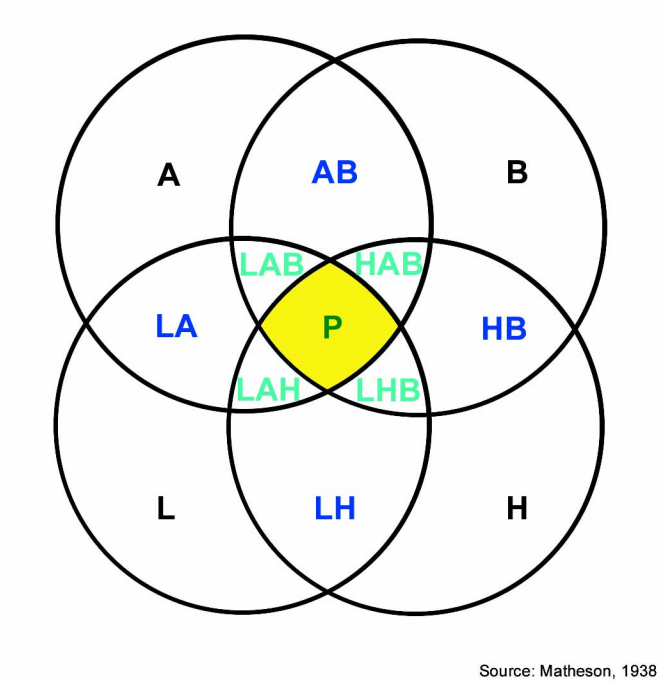


Fig. 1.4. Formation of two-sphere, three-sphere and four-sphere systems in nature. The pedosphere (P) is a four-sphere system (Adapted from Mattson, 1938).

Examples of two-sphere and three-sphere systems from different combinations of the lithosphere, the hydrosphere, the atmosphere and the biosphere are presented below:

1. **LA: Lithosphere + Atmosphere Systems.** These can be found in barren, hot deserts or dried river beds where the dispersed system consists of mineral particles and air. Water is the major limiting factor for the establishment of living organisms in these systems.

2. **AB: Atmosphere + Biosphere Systems.** Organisms living on the soil surface in a dry area. For example, termites growing inside a piece of straw encrusted with soil particles in semi-arid tropical areas.

3. **HB: Hydrosphere + Biosphere Systems.** A pond or water with its organisms in the water column. This system has neither mineral particles nor free air.

4. **LH: Lithosphere + Hydrosphere Systems.** Water logged sand or clay materials in saturated, unweathered rock. This system has neither organisms nor air.

5. **LAH: Lithosphere + Atmosphere + Hydrosphere Systems.** A systems with earth, air and water but devoid of life due to extreme environmental conditions, e.g. high salt concentrations or the presence of toxic elements.

6. **LAB: Lithosphere + Atmosphere + Biosphere Systems.** There cannot be life without water but remains of biota in dry places may come close to this. For example, microorganisms which live in the pore spaces of rocks in hot deserts. Their metabolism shuts down when the relative humidity drops as the temperature of the rocks increases during the daytime.

7. **HAB: Hydrosphere + Atmosphere + Biosphere Systems.** Organic soils develop unsaturated conditions because the rate of accumulation of organic material is greater than the rate of decomposition. Organic soils do not have the lithosphere component in the top 50 cm.

8. **LHB: Lithosphere + Hydrosphere + Biosphere Systems.** Water logged soils and lake bottoms that have dissolved air but not free air.

Applications

The pedosphere is a four-sphere system in which there is a dynamic interaction of minerals, organic matter, air and water. Here are some examples to illustrate systems which may lead to the formation of soil.

1. In the northern areas of Pakistan, old dried river beds with sandy and gravelly materials are brought into agricultural use by building rock terraces, which are irrigated, fertilized with manure and seeded with legumes, such as alfalfa. The objective of these practices is to convert sandy parent materials into soil which will sustain agricultural production. Before the application of these techniques, the parent material corresponded to a two-sphere system of lithosphere and atmosphere. The addition of water, nutrients and living organisms and plants converts this two-sphere system into a four-sphere system. Alfalfa is grown for at least five years to build soil structure, and increase the nutrient supplying power and water holding capacity of this sandy parent material. Eventually, the soil is able to support the growth of other crops, such as wheat.

2. Saline parent materials have high pH and high concentrations of sodium ions. In some mining operations, these materials are deposited on the surface of the landscape. If there is adequate rainfall, salts are leached out and plants are able to grow in these soils. The introduction of plants can eventually lead to the formation of soil. In this case a three-sphere system (lithosphere, atmosphere and hydrosphere) is converted to a four-sphere system.

3. The contamination of a soil by oil can lead to the formation of hydrophobic soils. These soils do not take up water and do not support plant growth. In this case, a four-sphere system is converted to a three-sphere system and the biological function is diminished due to a lack of available water.

4. Severe wind and water erosion can lead to loss of the A and B horizons of shallow soils. Restoration of such severely eroded soils (three-sphere systems consisting of lithosphere, atmosphere and hydrosphere) is difficult because the parent materials do not have favorable conditions for plant growth. The reclamation of such soils can take decades or centuries, depending upon the management techniques applied to convert this system back to a four-sphere system. Producers are extremely aware of the long-term loss of crop productivity on severely eroded soils and conserve the surface horizons of soils through proper management.

1.3 Pedosphere/Soilscape Relationships

Definitions

Landscape: All the natural features such as fields, hills, forests, and water that distinguish one part of the earth's surface from another part. Usually it is the portion of land or territory that the eye can see in a single view, including all its natural characteristics.

Pedology: The aspects of soil science dealing with the origin, morphology, genesis, distribution, mapping, and taxonomy of soils, and classification in terms of their usage.

Soilscape: A pedological portion of the landscape. A soilscape is commonly viewed from a vantage point in the landscape rather than from above it.

Soil polypedon: A soil volume, in situ, which consists of more than one pedon, is termed a polypedon. A soil body on the landscape is a true soil individual and is a concrete example of the polypedon concept. A soil polypedon is also called a soil individual or a soil body.

Soil pedon: The smallest volume of what can be called a soil. A pedon has 3 dimensions. Its lower limit is the vague and somewhat arbitrary limit between soil and "not soil". Its area ranges from 1 to 10 square meters, depending upon the variability of horizons. The shape of the pedon is roughly hexagonal.

Soil profile: A vertical section of the soil through all its horizons and extending into the parent material. It has two dimensions.

Soil horizon: A layer of soil or soil material approximately parallel to the land surface; it differs from adjacent genetically related layers in properties such as color, structure, texture, consistence, and chemical, biological, and mineralogical composition.

Soil solum: The upper horizons of a soil in which the parent material has been modified and in which most plant roots are contained. It usually consists of A and B horizons.

Soil ped: A unit of soil structure, such as a prism, block, or granule, which is formed by natural processes, in contrast with a clod, which is formed artificially.

Soil aggregate: A group of soil particles cohering in such a way that they behave mechanically as a unit.

Concepts

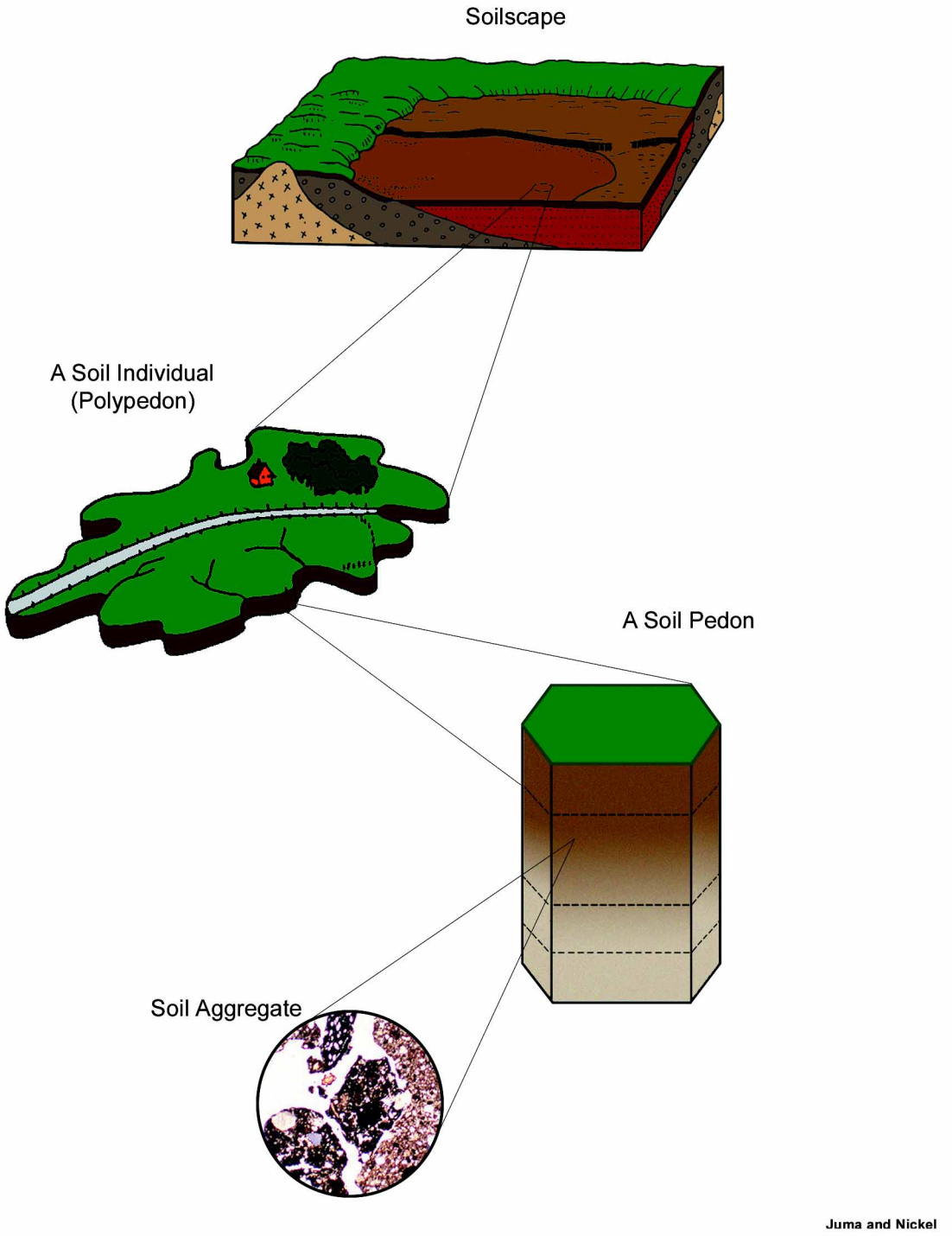


Fig 1.5. Hierarchical arrangement of different components of a soilscape (after Buol et al. 1989). Reproduced with permission from Iowa State University Press, Ames.

A soil pedon is a three-dimensional conceptual unit used by pedologists. In contrast, soil polypedons are related to three-dimensional natural soil bodies in the landscape. The pedon, polypedon (soil body) and landscape approach of studying soils permits the study the dynamics of air, water, nutrients, pollutants, and energy. Soils are open, dynamic systems and respond to natural processes and human activities.

1.4 Soil as an Open System

Definitions

Biocycling: The cycling of materials through microorganisms, plants and animals.

Insolation: The amount of incoming solar radiation that is received over a unit area of the Earth's surface. This varies according to season, latitude, transparency of the atmosphere, and aspect or ground slope.

Reradiation: To emit (energy) in the form of radiation after absorbing incident radiation.

Precipitation: The deposition of hail, mist, rain, sleet, or snow onto the earth.

Evapotranspiration: The combined loss of water from a given area, and during a specified period of time, by evaporation from the soil surface and by transpiration from plants.

Deposition: The addition of materials to the surface.

Erosion: The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. Erosion can also involve the detachment and movement of soil or rock by water, wind, ice, or gravity.

Translocation: The movement of soil materials in solution or suspension from one horizon to another.

Transformation: The process of changing the form of a substance.

Lateral gains: The entry of materials into a pedon from the side.

Lateral losses: The loss of materials from a pedon through the side.

Weathering: The breakdown of rocks and minerals at and below the Earth's surface by the action of physical and chemical processes.

Leaching: The removal from the soil of materials in solution.

Solute: A dissolved substance.

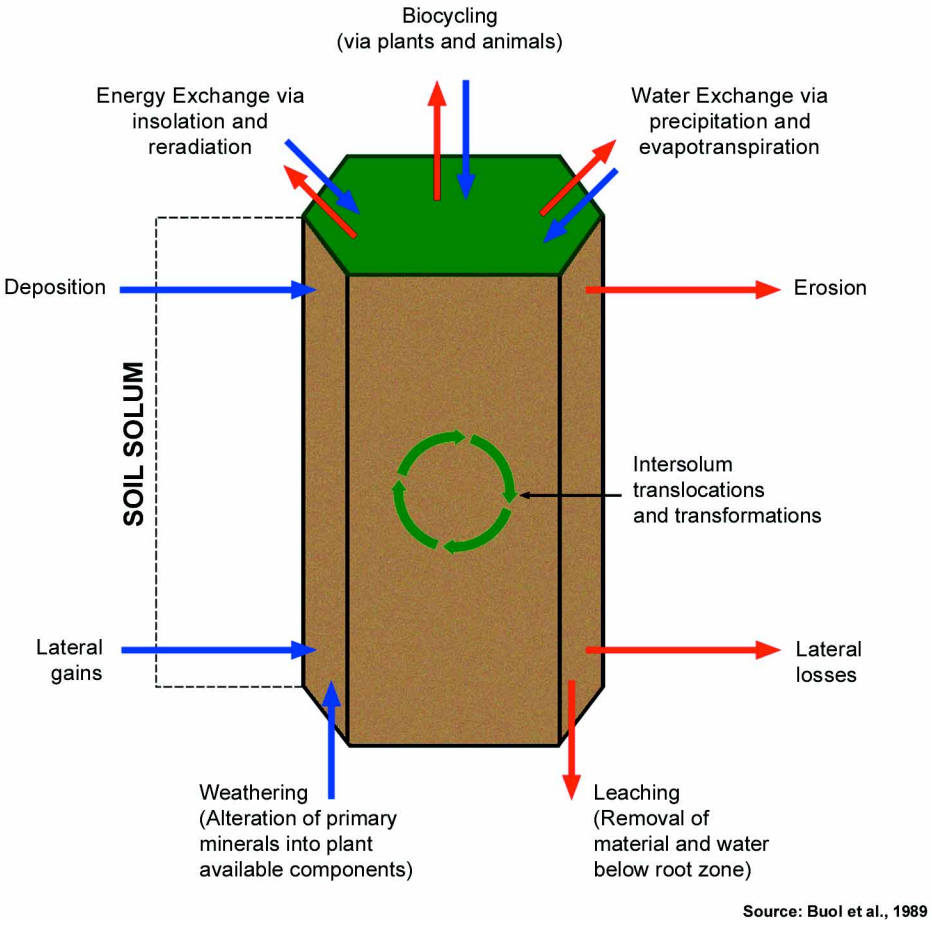


Fig. 1.6. Schematic representation of the solum of a soil pedon as an open system (after Buol et al. 1989). Reproduced with permission from Iowa State University Press, Ames.

Concepts

A soil has a budget of inputs and outputs and exchange gases (oxygen, carbon dioxide, water vapor, methane, nitrous oxides) with the atmosphere. Soluble materials (nitrate, soluble organic carbon) leach out of some soils. The physical, chemical, and biological processes operating in and on the soil result in an unequal distribution of materials in the individual horizons and soil bodies. Deposition and erosion of materials result in redistribution of materials in a soilscape.

Applications

Ecosystems exchange water, carbon dioxide, oxygen and nitrogen with the atmosphere; and ions with the lithosphere (Fig.1.7). Water is the major transport agent for fluxes within and between terrestrial ecosystems. It is a prerequisite for all active life, and participates in geochemical cycles by weathering geological substrates, by leaching materials to groundwater and by moving ions and

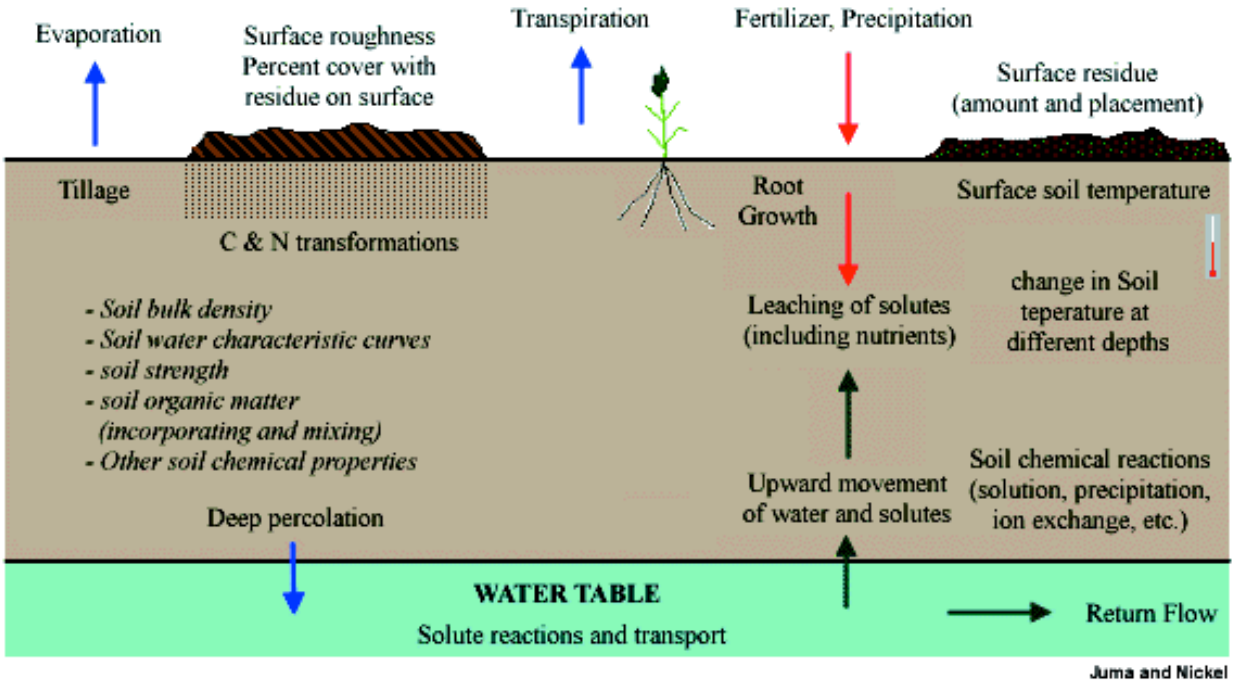


Fig. 1.7. Agroecosystem properties and processes.

particles through the soil profile. Plants and other organisms within soil alter the suite of solutes in percolating water which reach the groundwater system. A dynamic equilibrium is maintained despite the fact that very different types of substances are exchanged and stored (Schulze and Zwolfer, 1987). Agricultural activity manipulates energy fluxes, nutrient dynamics and hydrologic cycles in agroecosystems. Some major perturbations include tillage, crop residue management, fertilization, selection of plant species, weed control and irrigation (Fig. 1.7). Processes such as evaporation, transpiration, decomposition, nutrient cycling, intersolum translocations and transformations occur in all soils. All these processes affect the ecological structure and function of agroecosystems. An understanding of the magnitude of physical, chemical and biological processes in soil can lead to better management of agroecosystems. It is clear that the increase of human population will lead to intensive use of soils around the world, and therefore, better management will be required.

1.5 Energy Flow in the Soil

Definitions

Convection: A vertical circulation within a fluid that results from density differences caused by temperature variations.

Conduction: The transfer of heat through matter by communication of kinetic energy from particle to particle with no net displacement of the particles.

Condensation: The conversion of a substance (such as water) from the vapor state to a denser liquid or solid state usually initiated by a reduction in temperature of the vapor.

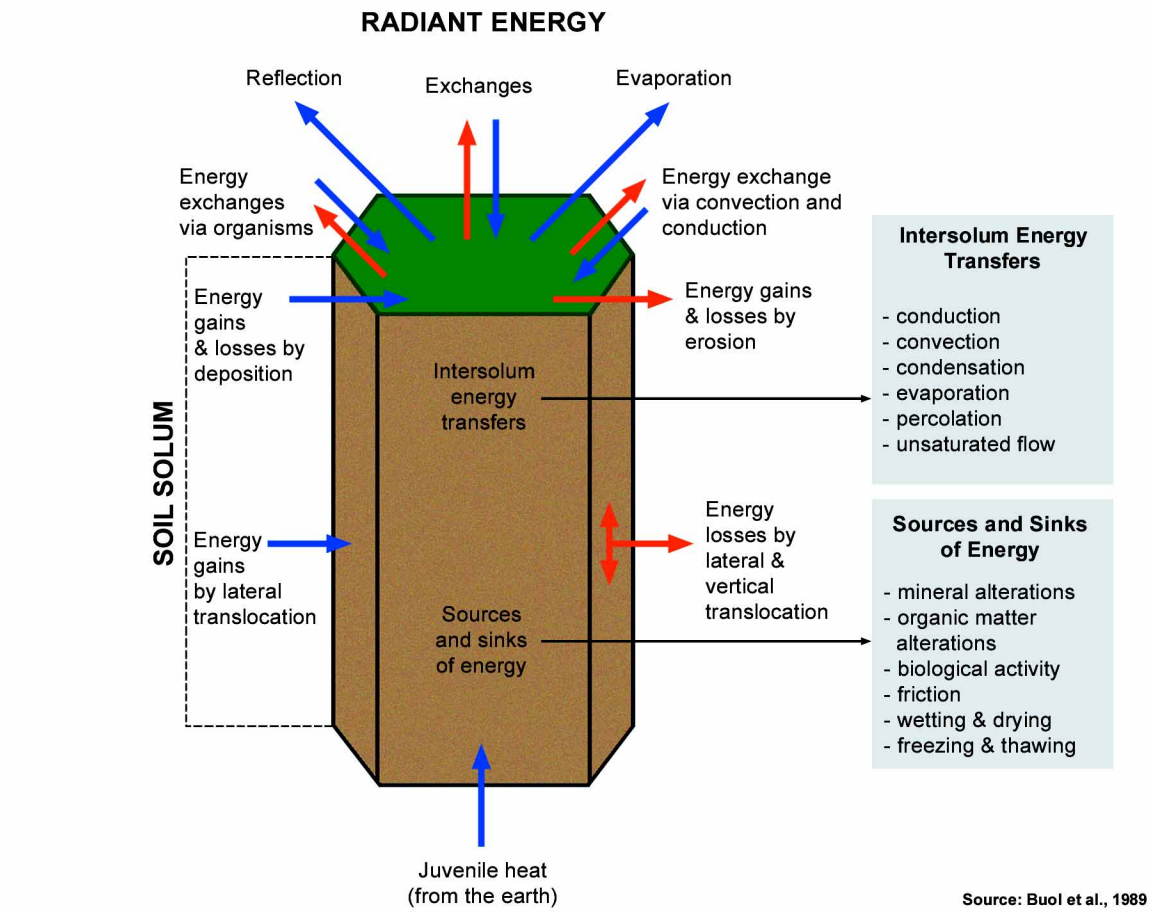


Fig. 1.8. Schematic representation of energy sources and transformations in the solum of a soil pedon (after Buol et al. 1989). Reproduced with permission from Iowa State University Press, Ames.

Concepts

The soil pedon is a three-dimensional entity in which numerous physical, chemical and biological processes take place. These processes are driven by changes in different kinds of energy (Fig. 1.8). For example, the erosion of a bare soil from an upper slope position and its deposition in a lower slope position of a landscape is related to changes in the kinetic energy of moving rain water on the soil surface. The diurnal temperature regime observed in soils is directly related to incoming solar radiation at the soil surface. A portion of solar energy is converted to heat energy, which results in an increase of soil temperature in the soil surface during the day. Soil temperature drops in surface soils during the evening and at night. The heat balance also determines the rate of weathering and soil formation, and the rate of biological activity in soil. A portion of radiant energy is converted to chemical energy by the process of photosynthesis and is stored in plants as carbohydrates. These carbohydrates are translocated to roots and deposited into soil by various processes such as exudation and fine root turnover. The chemical energy added to soil in the form of carbon compounds supports the food web in soil. All of the above examples show that that the pedon is a reactor in which energy is added, organic materials and minerals are decomposed and resynthesized, and materials and energy enter and leave the system.

Applications

The concepts of energy flow and transformation in ecosystems have been described by Aldo Leopold (1966) as follows:

> *Land, then, is not merely soil; it is a fountain of energy flowing through a circuit of soils, plants, and animals. Food chains are the living channels that conduct energy upward; death and decay return it to the soil. The circuit is not closed; some energy is dissipated in decay, some is added by absorption from the air, some is stored in soils, peats, and long-lived forests.*

1.6 Major Components of Soil

Definitions

Mineral: A usually inorganic substance which occurs naturally, and typically has a crystalline structure whose characteristics of hardness, luster, color, cleavage, fracture and relative density can be used to identify it. Each mineral has a characteristic mineral composition. Rocks are composed of minerals.

Weathering: The breakdown of rocks and minerals at and below the Earth's surface by the action of physical and chemical processes.

Biogeochemical cycle: The movement of chemical elements from organism to physical environment to organism in more or less circular pathways.

Decomposition: The breakdown of complex organic molecules of dead protoplasm and cell walls into simpler organic and inorganic molecules, which may be used again by other organisms.

Nutrient cycle: A biogeochemical cycle in which inorganic nutrients move through the soil, living organisms, air, and water or through some of these.

Ecosystem: A discrete unit that consists of living and nonliving parts, interacting to form a stable system. Fundamental concepts include a flow of energy via food chains and food webs, and the cycling of elements biogeochemically.

Ion: Atom, a group of atoms or a compound that is electrically charged as a result of the loss of electrons (cation) or the gain of electrons (anion).

Solute: A dissolved substance.

Percolation: The downward movement of water through soil, especially through soil that is saturated or close to saturation.

Groundwater: Water that is passing through or standing in the soil and the underlying strata. It is free to move by gravity.

Equilibrium: A state of balance between opposing forces or actions that is either static (as in a body acted on by forces whose resultant is zero) or dynamic (as in a reversible chemical reaction when the velocities in both directions are equal).

Metabolism: The total of all the chemical reactions that occur within a living organism.

Concepts

The pedosphere is a dispersed system confined to the surface of the earth because it is only here that the lithosphere, the hydrosphere, the atmosphere and the biosphere come in contact and interact with one another. The constitution of the pedosphere varies with the proportions of the spheres and the intensity of physical, chemical and biological processes occurring within individual pedons. Thus, the lithosphere dominates in mineral soil, the biosphere dominates in organic soils, the hydrosphere dominates wet soils and the atmosphere dominates dry, porous soils (Mattson, 1938).

The arrangement of soil pores and soil aggregates can be studied by micromorphological methods. An image of an undisturbed cross-section of soil (a soil thin section) obtained with a microscope shows the arrangement of solids and pores in soil (Fig. 1.9). The pores are filled with air or water, while the solids are composed of mineral matter and living and nonliving organic materials.

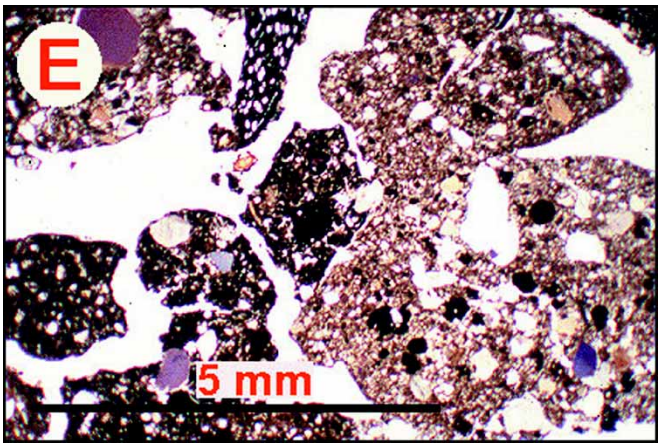


Fig 1.9. Distribution of organic and mineral materials, and pores in a soil thin section. Reproduced with permission from S. Pawluk, University of Alberta, Edmonton.

The fundamental components of soil are minerals, organic matter, water and air. Mineral particles are inorganic materials derived from rocks and are extremely variable in size. The weathering of minerals affects the composition of the soil solution because it can contain plant nutrients as well as toxic substances. The rate of weathering is affected by the size and composition of minerals, soil pH, temperature, biotic activity, water and air content. The description of mineral components is an integral part of soil profile descriptions of mineral soils.

Soil organic matter consists of living organisms (soil biomass), the remains of organisms, and organic compounds produced by current and past metabolism in the soil. The soil biota, consisting of microorganisms, soil fauna and plants, form a food web in soil and control the decomposition of plant and animal residues, anthropogenic compounds, and a wide variety of organic compounds added to the soil. The food web also controls nutrient cycling and contributes to the formation of soil structure. The organic materials modified or transformed by soil organisms react with the mineral component of soils to form organo-mineral complexes and soil aggregates. Soil organic matter also affects the fundamental physical, chemical and biological properties of soil.

Water is the major transportation agent for fluxes within and between terrestrial ecosystems. It is a prerequisite for all active life, and participates in geochemical cycles by weathering geological substrates, by leaching materials to groundwater and by moving ions and particles through the soil profile. Plants and other organisms within soil alter the suite of solutes in percolating water which reaches the groundwater system. A dynamic equilibrium is maintained in soil because different types of substances are exchanged and stored.

The pore space, which is not occupied by minerals, organic matter or living organisms, is filled with air or water in soil. There is a dynamic equilibrium between water and air content within soil. When water enters the soil, it displaces air from some of the pores. The composition of soil air is different from the atmosphere above the soil because soil air cannot readily mix with the air above the soil. Soil air composition is altered by the metabolic activity of plant roots, microbes and soil fauna. For example, carbon dioxide in soil air is often several hundred times more concentrated than the 0.03% found in the atmosphere. The amount and composition of air in a soil are determined to a large degree by the water content of the soil.

The soil is not merely the sum of minerals, organic matter, water and air but the product of their interactions. These will be discussed in a greater detail in other sections of this book.

1.7 Soil Profiles

Definitions

Eluviation: The transportation of soil material in suspension or in solution within the soil by the downward or lateral movement of water.

Eluvial horizon: A soil horizon that has been formed by the process of eluviation.

Illuviation: The process of depositing soil material removed from one horizon in the soil to another, usually from an upper to a lower horizon in the soil profile. Illuviated substances include silicate clay, hydrous oxides of iron and aluminum, and organic matter.

Illuvial horizon: A soil horizon in which material carried from an overlying layer has been precipitated from solution or deposited from suspension as a layer of accumulation.

Hydrolysis: The process by which a substrate is split by the intervention of a molecule of water to form two end products.

Reduction: A reaction in which atoms or molecules either lose oxygen or gain hydrogen or electrons.

Oxidation: A reaction in which atoms or molecules gain oxygen or lose hydrogen or electrons.

Gley: The product of waterlogged soil conditions, and hence an anaerobic environment; it encourages the reduction of iron compounds by microorganisms and often causes the mottling of soil into a patchwork of gray and rust colors. This process is known as gleying.

A horizon: A mineral horizon formed at or near the surface in the zone of removal of materials in solution and suspension, or maximum in situ accumulation of organic carbon, or both.

B horizon: A mineral horizon characterized by one or more of the following:

1. An enrichment in silicate clay, iron, aluminum, or humus.
2. A prismatic or columnar structure that exhibits pronounced coatings or stainings associated with significant amounts of exchangeable sodium.
3. An alteration by hydrolysis, reduction, or oxidation to give a change in color or structure from the horizons above or below, or both.

C horizon: A mineral horizon comparatively unaffected by the pedogenic processes operative in A and B, except gleying, and the accumulation of carbonates and more soluble salts.

Concepts

O Organic horizons (>17% organic carbon) found in Organic soils and commonly at the surface of wet mineral soils

A Surface or near surface mineral horizons showing evidence of eluviation and/or in situ accumulation of organic matter.

B Mineral horizons characterized by enrichment of illuvial organic matter, sesquioxides or clay; or by the development of soil structure; or by a change in coloring showing evidence of hydrolysis, reduction or oxidation.

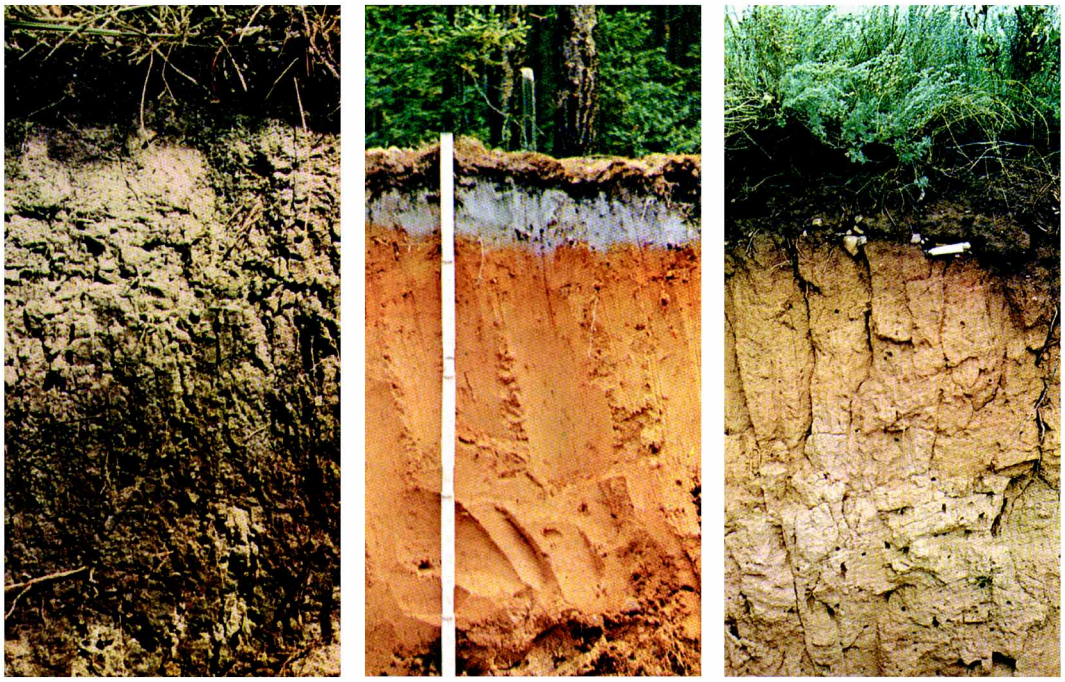
C Mineral horizons unaffected by pedogenic processes except for gleying and the accumulation of carbonates and soluble salts.

Fig. 1.10. Soil profile showing master horizons and the dominant processes that lead to their development.

Soil profiles show the master horizons and evidence of the dominant processes that led to their development. Generally, A, B, and C are master mineral horizons and O or LFH are master organic horizons. While some pedons may not have all these horizons, all pedons have some of them.

Applications

Soil landscapes evident around us are the product of soil forming factors acting on surface geological deposits over time. Factors influencing soil formation (or soil development) include kind of parent material, topography (or surface form), climate, vegetation, and activities of man acting over a period of time. The surficial deposit which comprises the parent material of soil is characterized by its physical and chemical properties such as soil texture (or mix of sand, silt, clay), reaction and salinity. Over time, this parent material is transformed to yield unique soils and soilscapes. Pictures of soil profiles that have developed in different parts of Canada are shown below:



Luvisolic (Alfisol) Podzolic (Spodosol) Chernozemic (Mollisol)

Fig. 1.11. Profiles of soils belonging to three different Canadian soil orders. The names in the brackets are corresponding names in the U. S. System of Soil Classification. The equivalent names in the World Reference Base for Soil Resources are Luvisol, Podzol and Chernozem.

A number of soil classification systems have been developed around the world. In this textbook, references will be made to the Canadian System of Soil Classification, the U. S. System of Soil Classification (also known as Soil Taxonomy) and the World Reference Base for Soil Resources. This is possible because taxonomic correlation tables at soil order and great group levels are now available. These are products of the tremendous effort of soil scientists and pedologists from around the world over a period of 40 years (1960-2000).

1.8 Summary

1. The pedologist is interested in the appearance of the soil, its mode of formation, its physical, chemical and biological composition, and its classification and distribution. The properties and distribution of patterns of soils worldwide are collectively termed the pedosphere.

2. The study of the connections and the interactions between the atmosphere, hydrosphere, biosphere, cryosphere, pedosphere, solid earth (lithosphere), and near space, in the context of global environmental change and the impact of human activities, is emerging as the foundation for Earth System Science.

3. The pedosphere (soils) only develops when there is interaction of the atmosphere, hydrosphere, lithosphere and the biosphere. The soil is not merely the sum of minerals, organic matter, water and air but the product of their interactions. These interactions can be studied at various scales of resolution: microscopic, horizon, pedon, landscape, regional and global.

4. The weathering of massive rocks along planes of weakness through physical and chemical processes leads to the formation of unconsolidated residues, called the regolith. The regolith occurs above the consolidated rock and is the material from which the soil forms.

5. Soils are open, dynamic, natural bodies in the landscape. They exchange water and air with the atmosphere, and ions and minerals with the lithosphere. Plants introduce reduced carbon, primarily in the form of sugars and carbohydrates, into soil and support the heterotrophic biomass in soil. Decomposition of these substrates results in their transformation and energy production, which is used to cycle nutrients through the soil system.

6. The soil pedon is a three-dimensional natural body in the landscape in contrast to a soil profile which is a two-dimensional view (length and depth) of soil. Examination of a soil profile reveals soil horizons that show evidence of physical, chemical and biological transformations of the regolith. The soil master horizons are named, starting from the surface downward, as A, B, and C horizons. The consolidated rock is called the R horizon. Soil pedons may have some or all of the master horizons.

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Interactive questions and answers for this chapter are incoroporated in the Pedology section of the Test Center. The URL for the Test Center is:

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